A SYSTEMIC RADIOMETRIC CALIBRATION APPROACH FOR LDCM AND THE LANDSAT ARCHIVE – An Update

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A SYSTEMIC RADIOMETRIC CALIBRATION APPROACH FOR LDCM AND THE LANDSAT ARCHIVE

- Consistent calibration of the Landsat archive through use of pseudo-invariant sites
- Techniques for relative gain calibration/correction of large linear arrays
- Vicarious calibration of LDCM and Landsat TM/ETM+ instruments

Techniques for relative gain calibration/correction of large linear arrays

- Relative Gain—whiskbroom to pushbroom scanner issue:
  - Landsat 4/5 TM—16 detectors/refl. band + 4 thermal det. → 100 det.
  - Landsat 7 ETM+ -- add the pan band & 30m thermal band → 136 detectors
  - Advanced Land Imager 320 multispectral detectors/sca x 4 sca's/band x 9 bands + 960 pan detectors/sca x 4sca's/band = 15,360 detectors
  - LDCM ≥ 57,000 detectors!

  Relative gain estimation is a critical element for LDCM!
- Methods to estimate Relative Gain
  - Image uniform fields
  - **Statistical based methods**
    - **Lifetime data sets**
    - **Individual scenes**
  - **90^{o} yaw maneuvers**

Relative Gain Estimation Techniques

- Lifetime Histogram Statistics Method
  - Over ‘long’ periods of time each detector observes the same data statistically.
  - Ratios of detector means or standard deviations can be used to estimate relative gains.
- Individual Scene Statistics Method
  - Odd/Even detector striping most prevalent due to focal plane design
  - Develop an objective function measuring odd/even striping
  - Use least squares approach to minimize objective function through estimation optimal relative gains.
- Yaw Data Sets
  - ‘Perfect’ 90^o yaw maneuver allows each detector to observe same point on the earth’s surface. Deterministic estimate of relative gain is possible.
  - Near 90^o yaw maneuver provides very uniform scene for relative gain estimate, but not perfect.
  - Use these data sets with statistical algorithms to develop a more accurate estimate of relative gains.

Theory of New Method

- Adjacent detectors see nearly the same data.
- Difference between adjacent detectors should be small.
- Develop function to minimize difference between adjacent detectors.

Symbols

- Q_{ij} – pixel value at point i, j (row, column).
- Q_{ij} – pixel value before relative gain correction (original value).
- r_j – relative gain for detector (column) j.
- $Q_{ij} = r_j\, Q_{ij}$.
- F(Q,r,i,j) – objective minimization function.

Setup Minimization Function F(Q,r,i,j)

$$\begin{matrix} Q_{11} & Q_{12} & \cdots & Q_{1m} \\ Q_{21} & Q_{22} & \cdots & Q_{2m} \\ \vdots & \ddots & \ddots & \vdots \\ Q_{n1} & \cdots & \cdots & Q_{nm} \end{matrix}$$

1 Band of 1 SCA
of an ALI Scene.

Minimize difference
between columns 1 and 2.

$$F(Q,r,i,1) = (Q_{11} - Q_{12}) + (Q_{21} - Q_{22}) + \cdots + (Q_{n1} - Q_{n2})$$

Square differences to
ensure positive numbers.

$$F^2(Q,r,i,1) = (Q_{11} - Q_{12})^2 + (Q_{21} - Q_{22})^2 + \cdots + (Q_{n1} - Q_{n2})^2$$

F(Q,r,i,j) Cont.

$$F^2(Q,r,i,1) = (Q_{11} - Q_{12})^2 + (Q_{21} - Q_{22})^2 + \cdots + (Q_{n1} - Q_{n2})^2$$

Expanding the Quadratics

$$Q_{11}^2 - 2Q_{11}Q_{12} + Q_{12}^2 + Q_{21}^2 - 2Q_{21}Q_{22} + Q_{22}^2 + \cdots + Q_{n1}^2 - 2Q_{n1}Q_{n2} + Q_{n2}^2$$

Express as a Sum of Products

$$\sum_i Q_{i1}^2 + \sum_i Q_{i2}^2 - 2\sum_i Q_{i1}Q_{i2}$$

Or in General

$$F^2(Q,r,i,j) = \sum_i Q_{ij}^2 + \sum_i Q_{ij+1}^2 - 2\sum_i Q_{ij}Q_{ij+1}$$

F(Q,r,i,j) Cont.

Recall

$$Q_{ij} = r_j Q^o_{ij}$$

Then Substituting

$$F^2(Q,r,i,j) = r_j^2 \sum_i {Q^o_{ij}}^2 + r_{j+1}^2 \sum_i {Q^o_{ij+1}}^2 - 2r_j r_{j+1} \sum_i Q^o_{ij} Q^o_{ij+1}$$

We now have a minimization function containing each detector relative gain.

From the above equation, we can see that each r_j appears in $F^2(Q,r,i,j-1)$ and $F^2(Q,r,i,j)$.

So each r_j appears in exactly 2 equations of the minimization function, except for r_1 and r_m which only appear in the first and last equations, respectively.

F(Q,r,i,j) Cont.

To minimize $F^2(Q, r, i, j)$, we differentiate it with respect to r_j.

$$\frac{\delta F^2(Q, r, i, j)}{\delta r_j} = 2r_j \sum_i Q_{ij}^{o^2} - 2r_{j+1} \sum_i Q_{ij}^{o} Q_{ij+1}^{o}$$

By setting this equal to zero we obtain.

$$r_j \sum_i Q_{ij}^{o^2} - r_{j+1} \sum_i Q_{ij}^{o} Q_{ij+1}^{o} = 0$$

We have a system of linear equations to solve for r_j.

F(Q,r,i,j) Cont.

Putting

$$r_j \sum_i Q_{ij}^{o^2} - r_{j+1} \sum_i Q_{ij}^{o} Q_{ij+1}^{o} = 0$$

in a matrix.

$$\begin{bmatrix} \sum_i Q_{i1}^{o^2} & -\sum_i Q_{i1}^{o} Q_{i2}^{o} & 0 & 0 & 0 & \cdots & 0 \\ 0 & \sum_i Q_{i2}^{o^2} & -\sum_i Q_{i2}^{o} Q_{i3}^{o} & 0 & 0 & \cdots & 0 \\ \vdots & \ddots & \ddots & \ddots & \ddots & \ddots & \vdots \\ 0 & \cdots & \cdots & \cdots & 0 & \sum_i Q_{im-1}^{o^2} & -\sum_i Q_{im-1}^{o} Q_{im}^{o} \\ 1 & \cdots & \cdots & \cdots & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} r_1 \\ r_2 \\ \vdots \\ r_{m-1} \\ r_m \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ m \end{bmatrix}$$

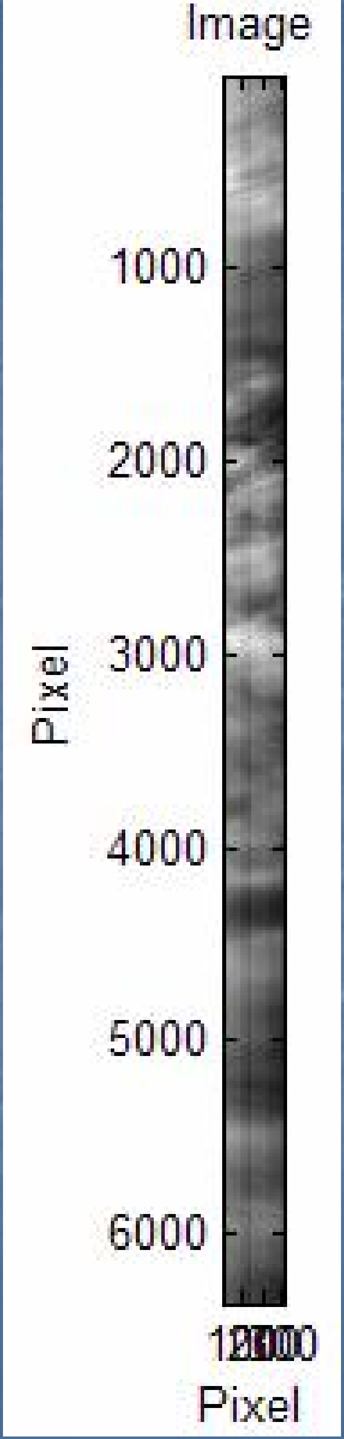
We can now solve for each r_j.

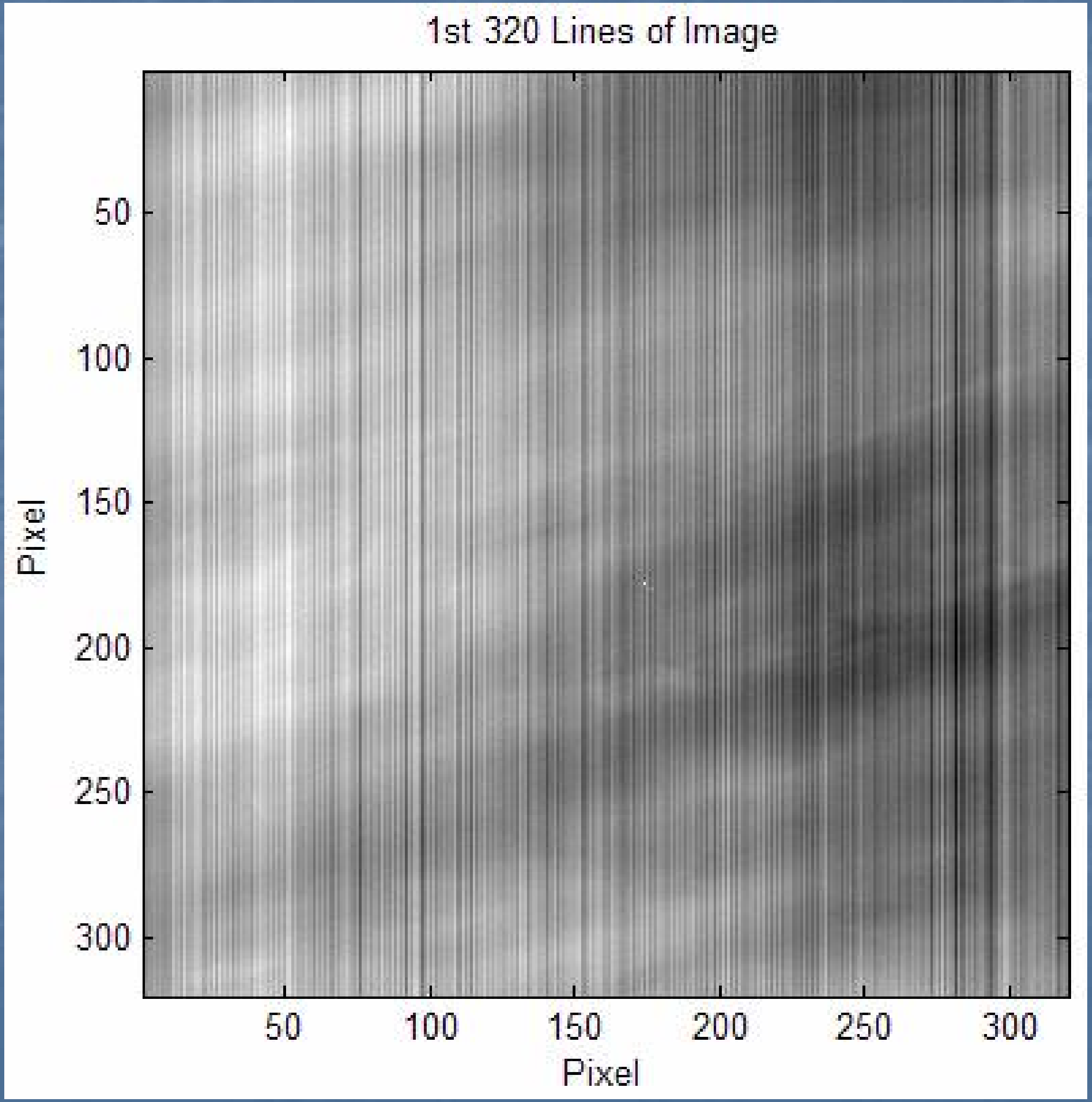
The last row of ones forces the mean of r_j to be equal to 1.

m = the number of columns (detectors) in the image.

Results

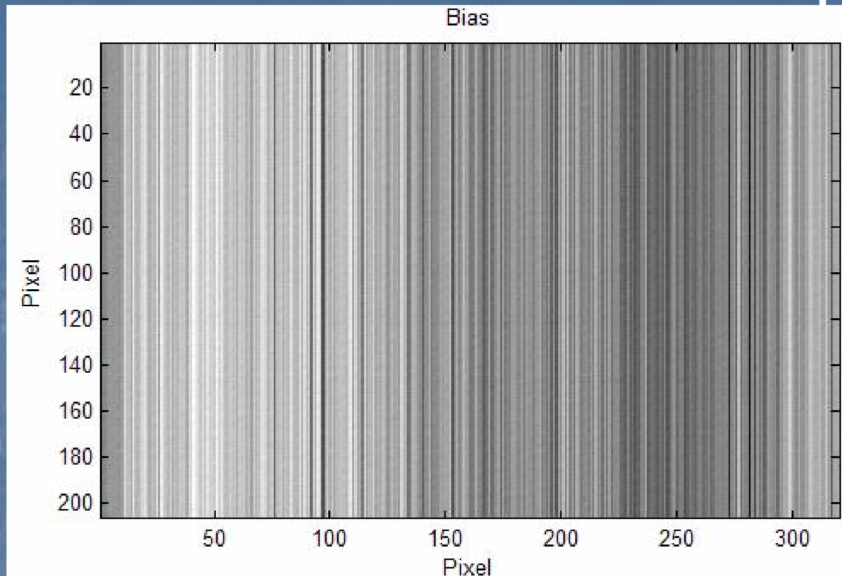
Scene: EO12001059230136_PF1_01 (Antarctica)
Band: 1p
SCA: 1

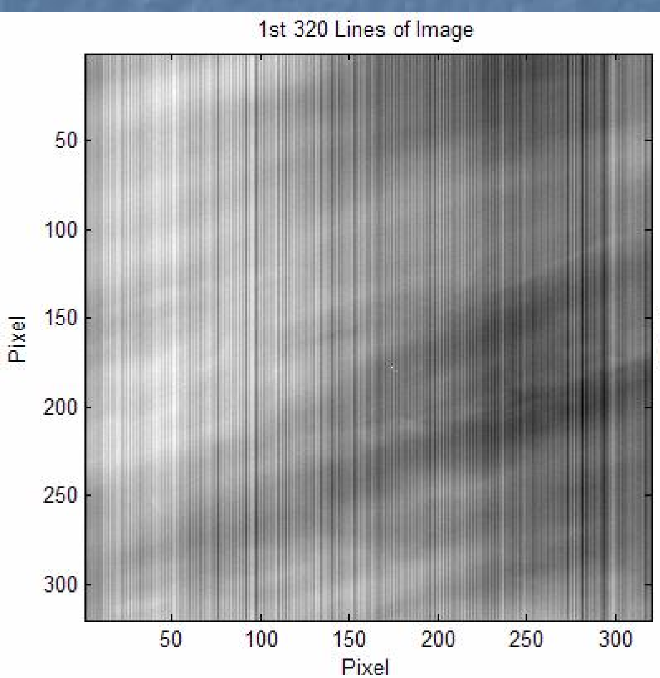


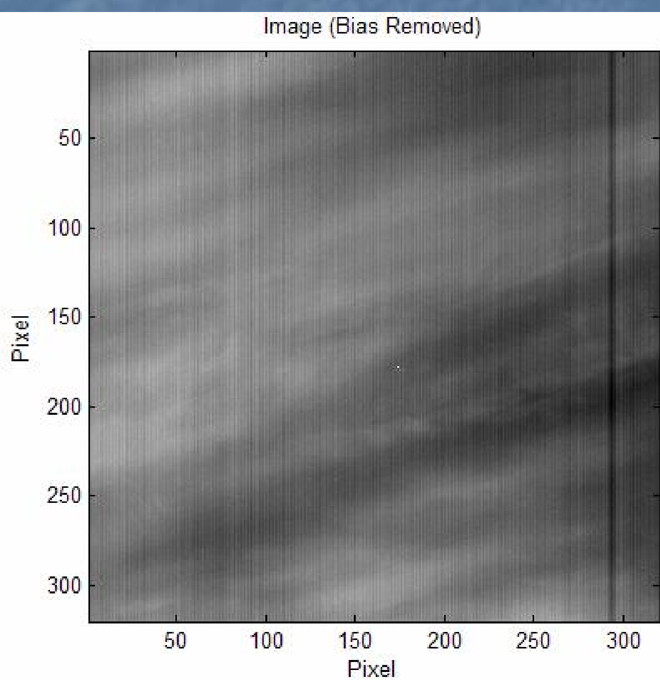


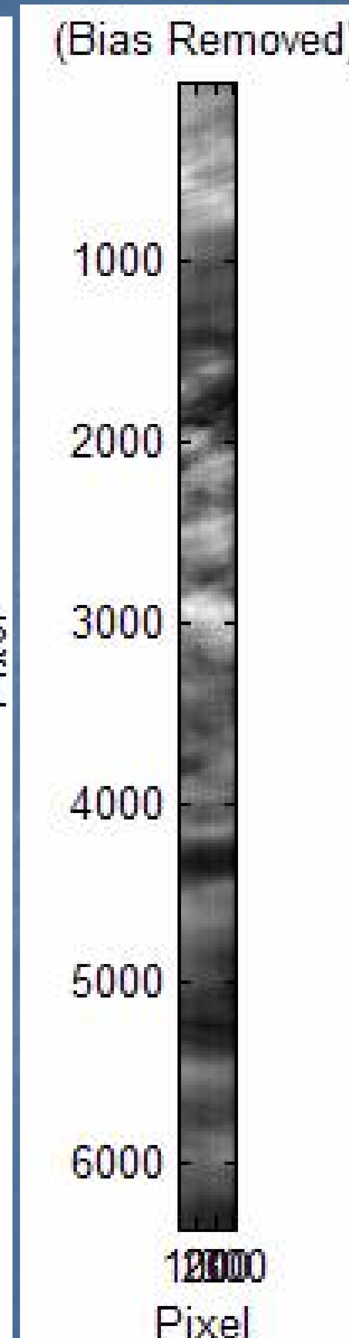
Remove Bias

Band 1p





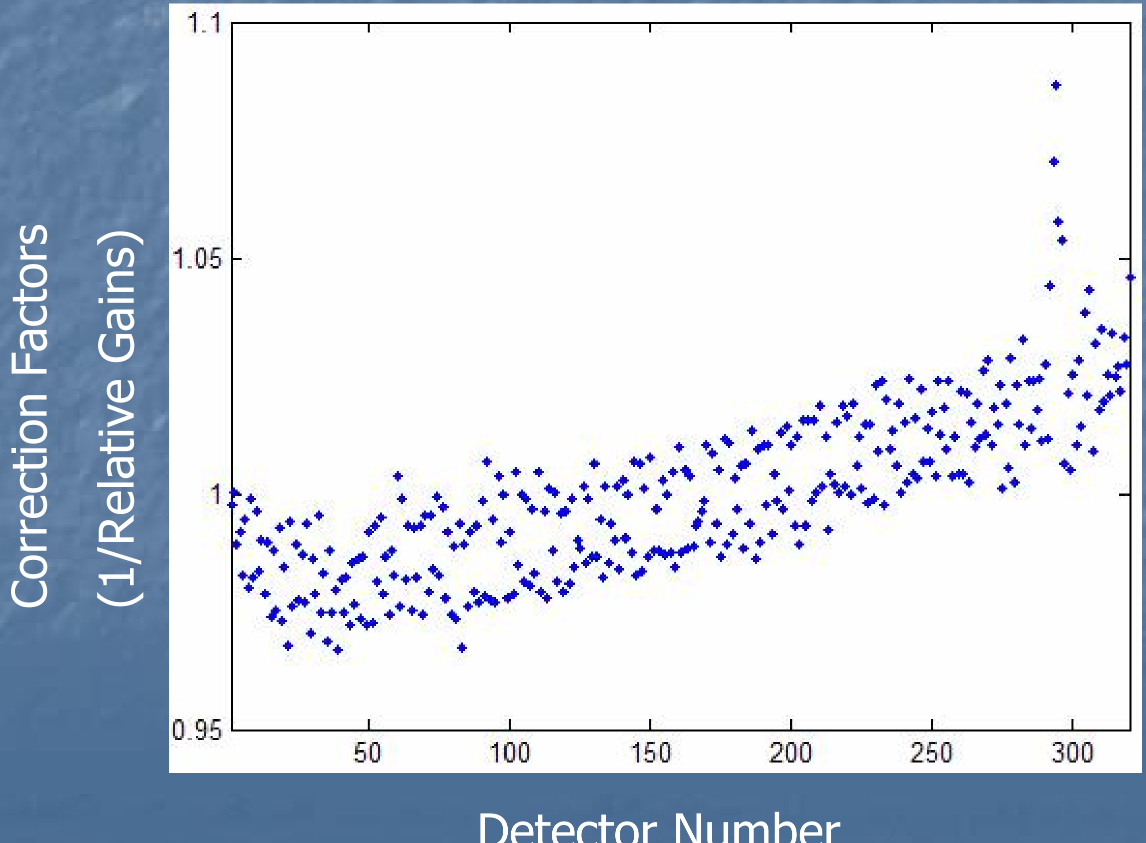




Correction Factors Using Image Statistics

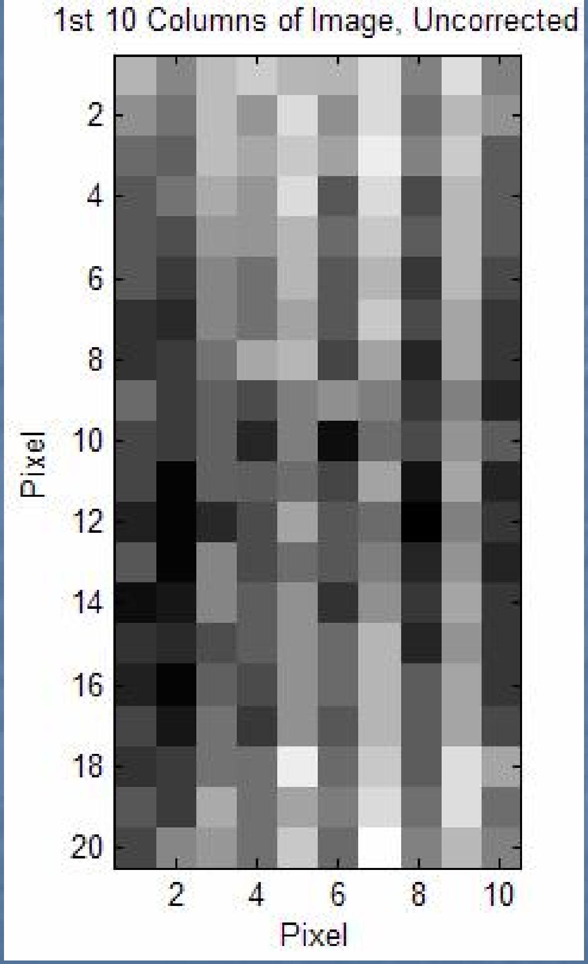
Band 1p

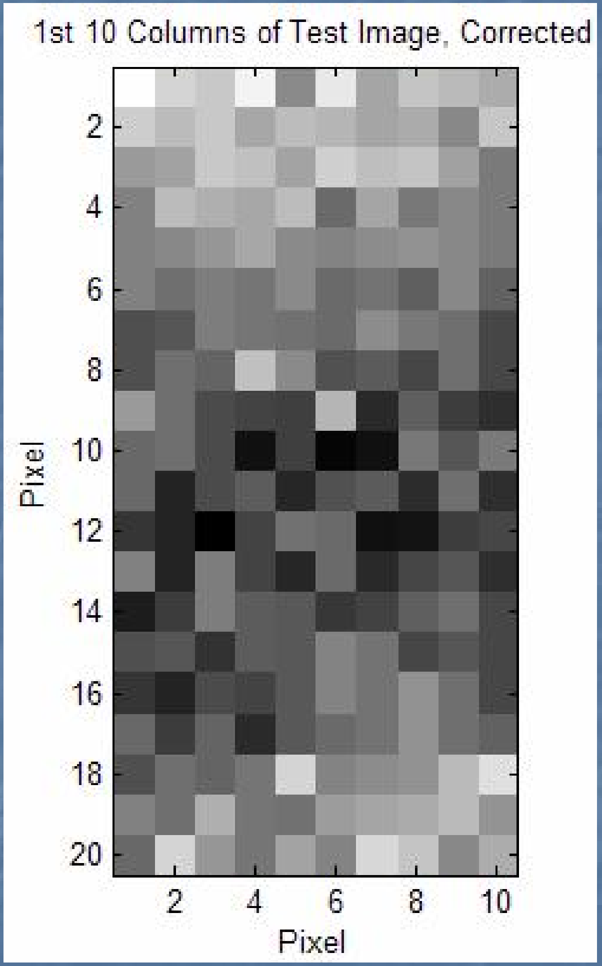
$$\begin{bmatrix} 503298569 & -502049150 & 0 & 0 & 0 & \cdots & 0 \\ 0 & 500829857 & -506218757 & 0 & 0 & \cdots & 0 \\ \vdots & \ddots & \ddots & \ddots & \ddots & \ddots & \vdots \\ 0 & \cdots & \cdots & \cdots & 0 & 481767608 & -473259943 \\ 1 & \cdots & \cdots & \cdots & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} r_1 \\ r_2 \\ \vdots \\ r_{319} \\ r_{320} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ 320 \end{bmatrix}$$



Corrected Image

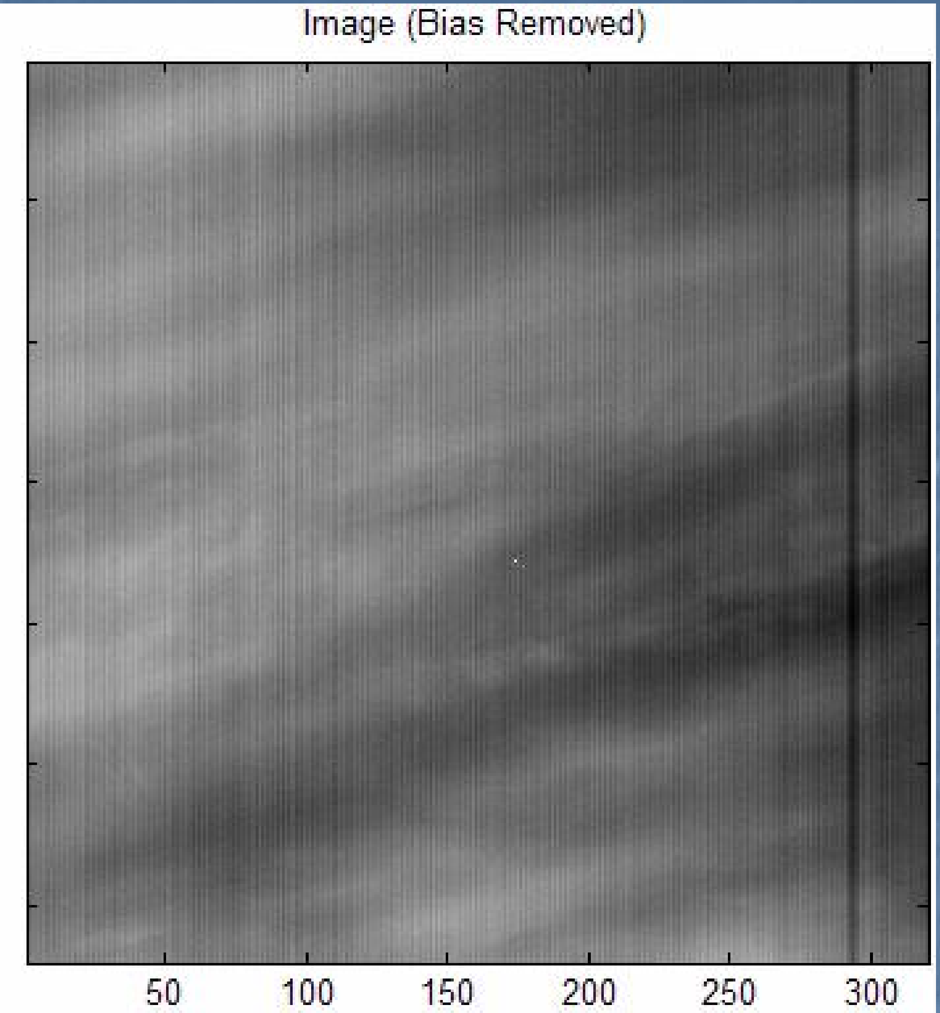
Band 1p

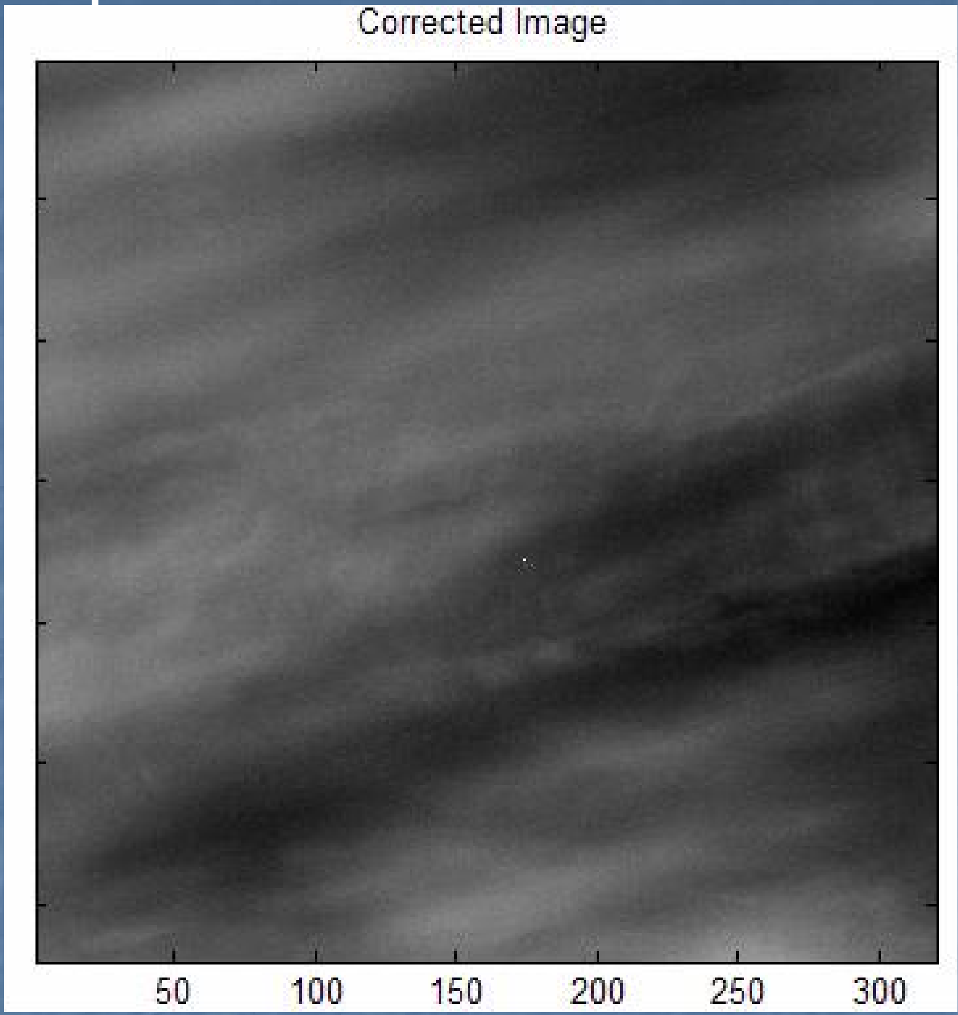




Corrected Image

Band 1p



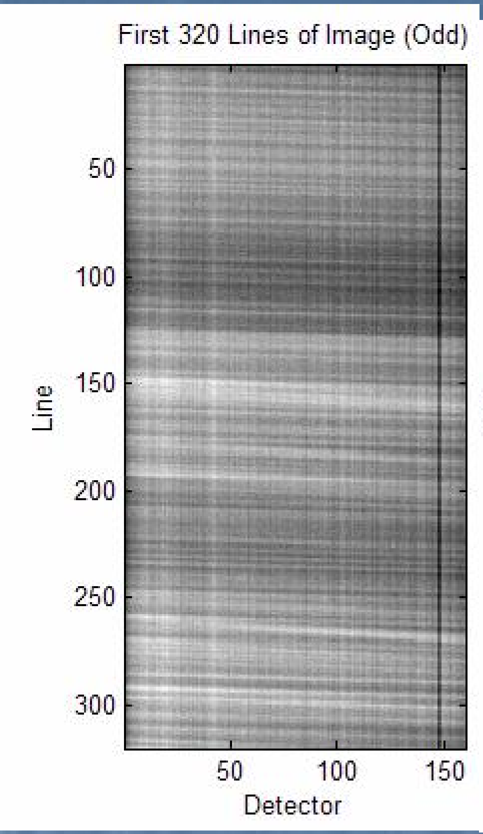


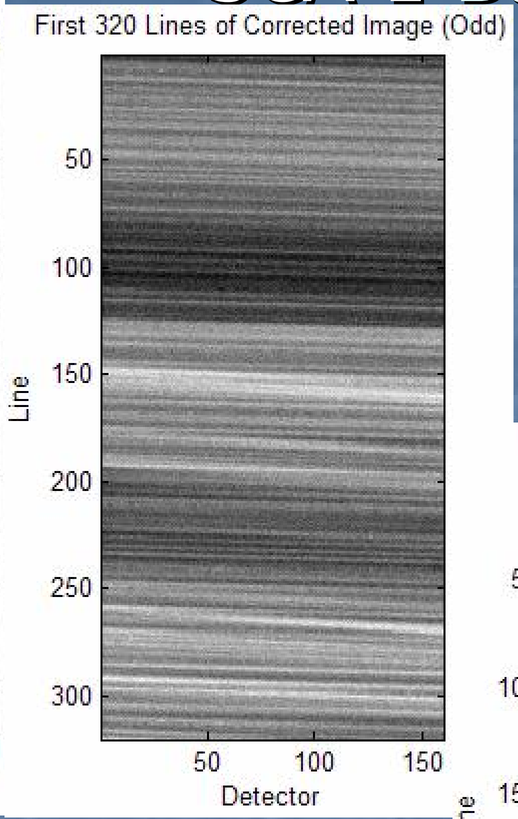
Data Range 263-384

Data Range 283-386

1st 320 Lines

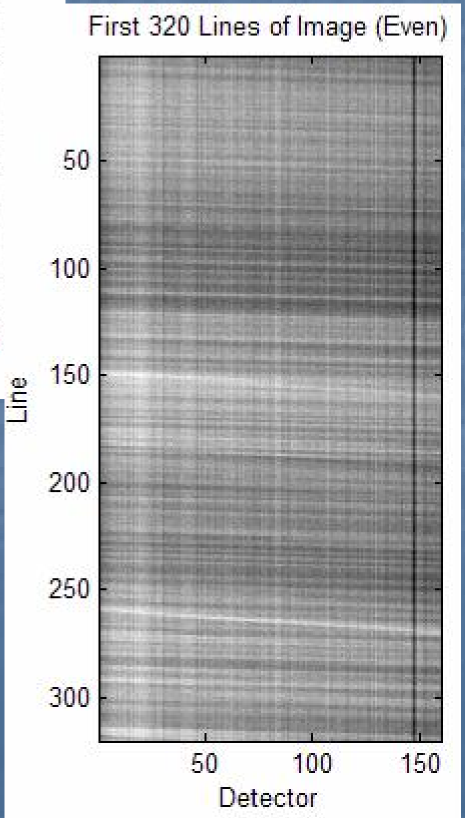
EO12004262105030_HGS – A YAW IMAGE SCA 1 Band 1p

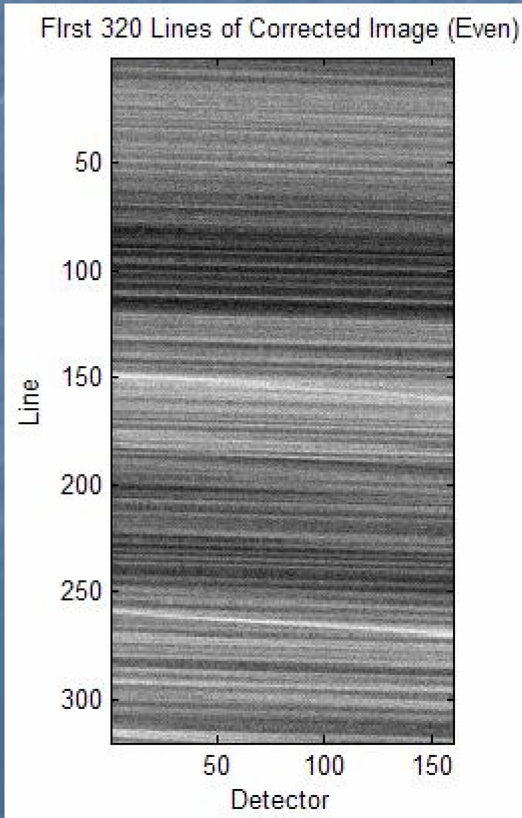




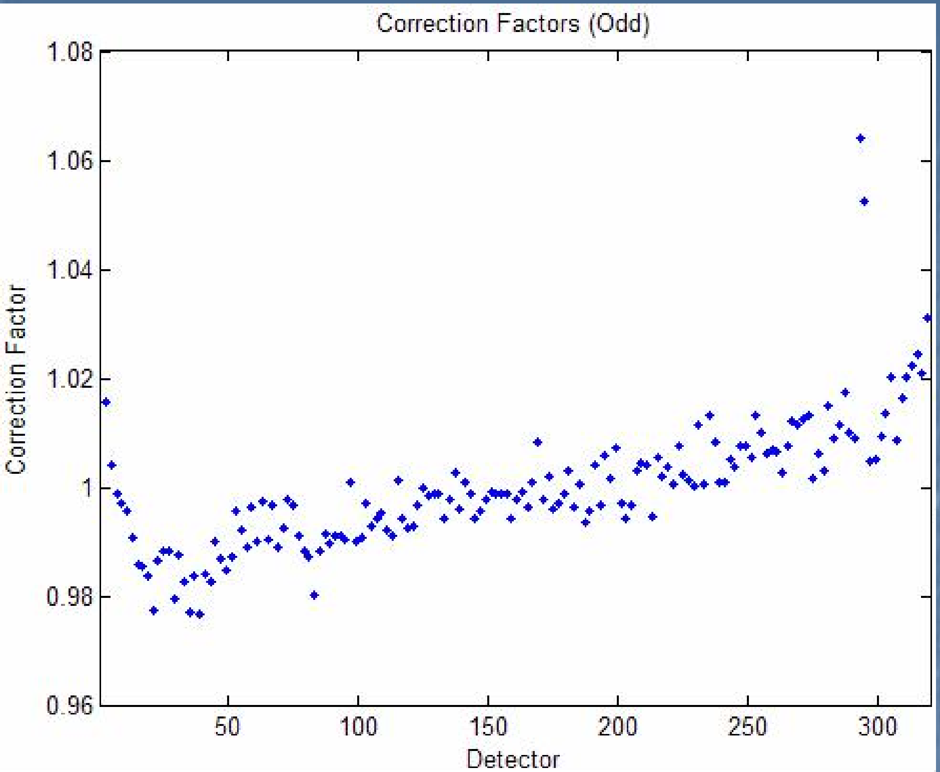
An example of a yaw image…

Yaw angle = 88.3^{o}

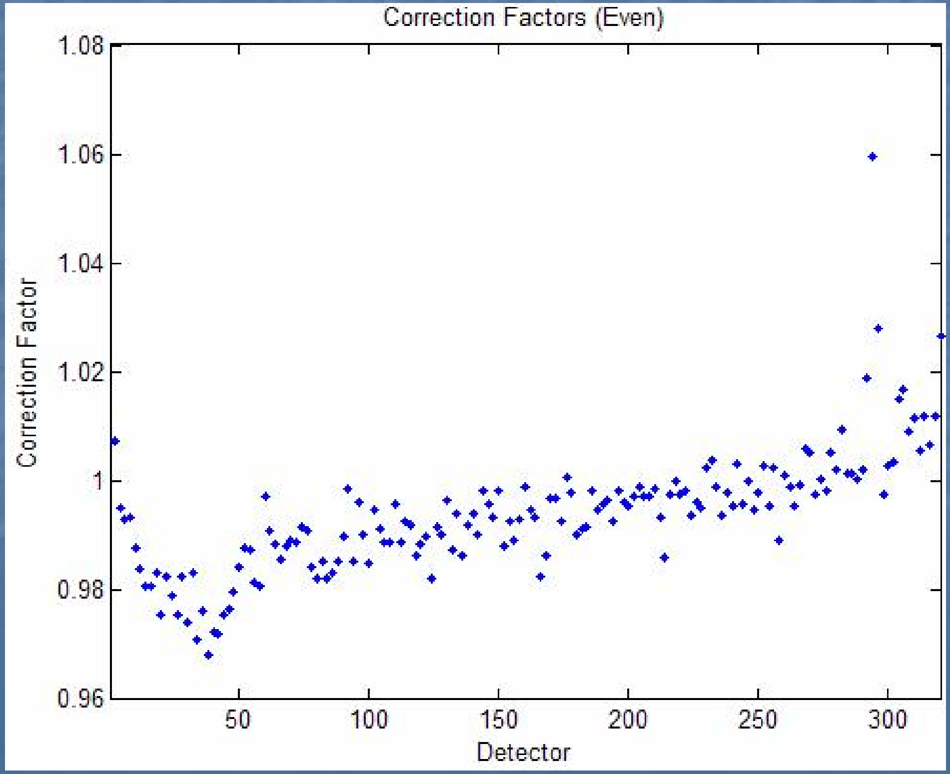




Band 1p Cont.



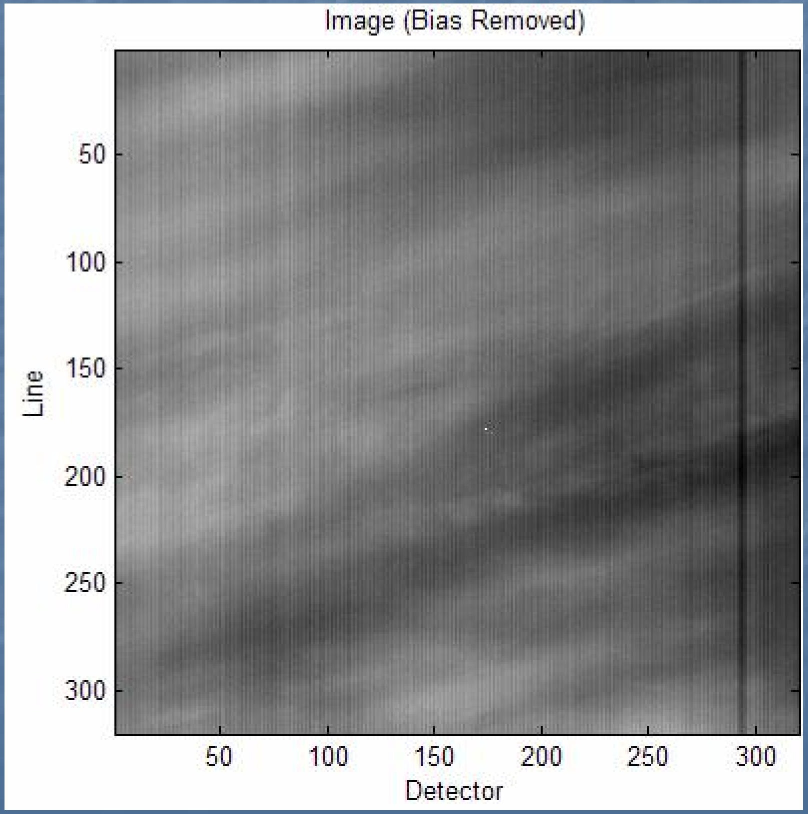
Correction Factors (Odd)
Correction Factor
Detector
1.08
1.06
1.04
1.02
1
0.98
0.96
50
100
150
200
250
300

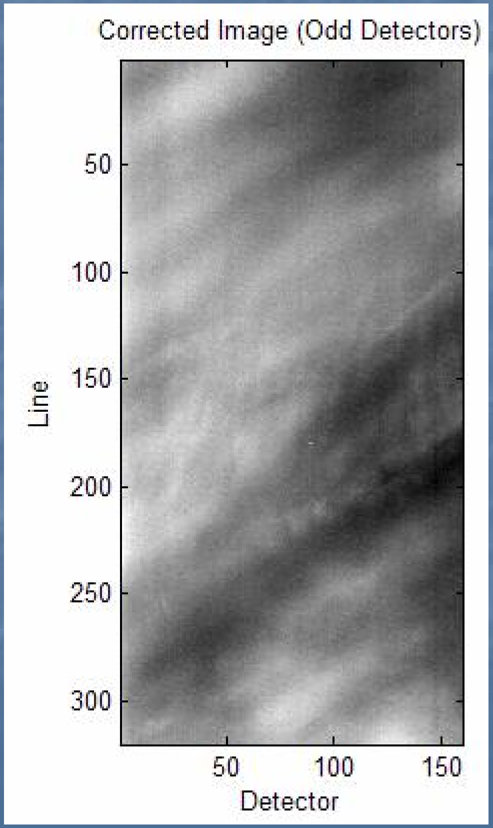


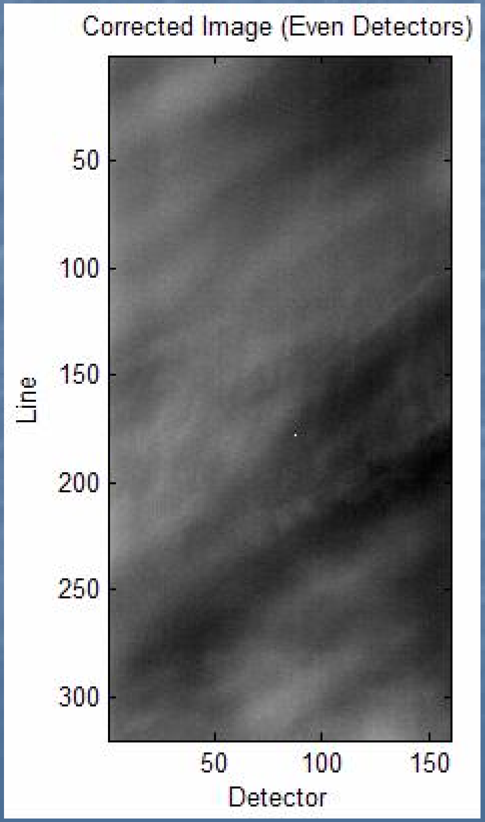
Correction Factors (Even)
Correction Factor
Detector
1.08
1.06
1.04
1.02
1
0.98
0.96
50
100
150
200
250
300

EO12004262105030_HGS Rel Gains Applied to EO12001059230136_PF1

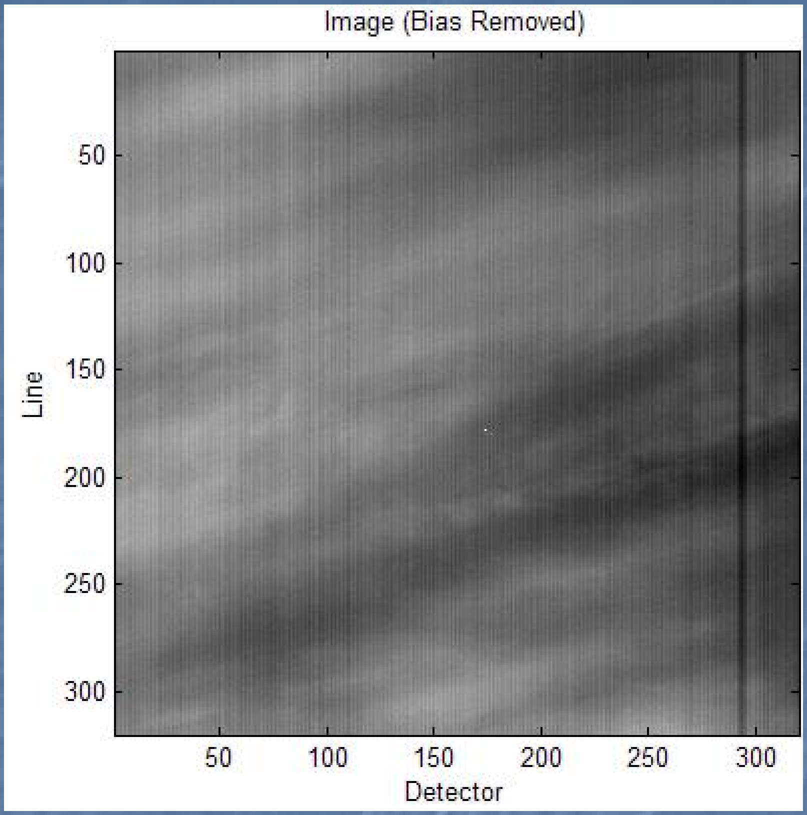
SCA 1 Band 1p



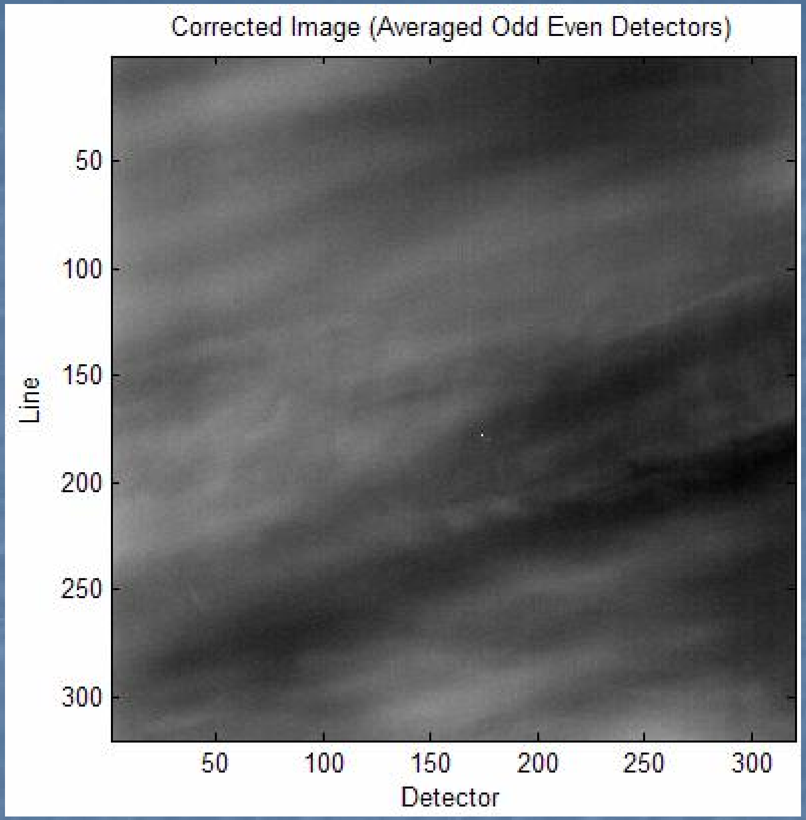




Band 1p Cont.



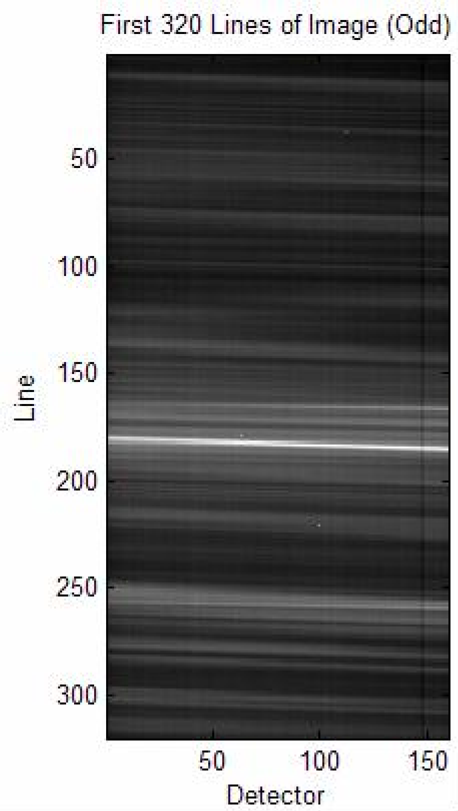
Data Range: 263-384

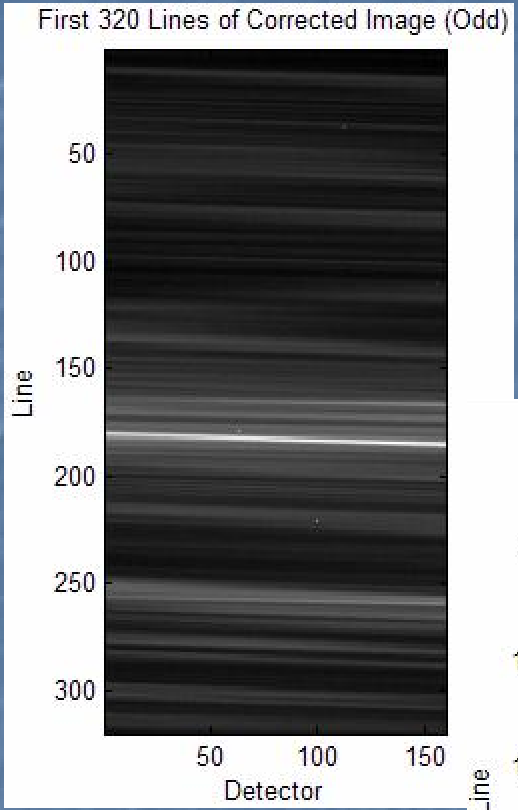


Data Range: 278-381

Even and Odd Detectors normalized by equalizing total means.

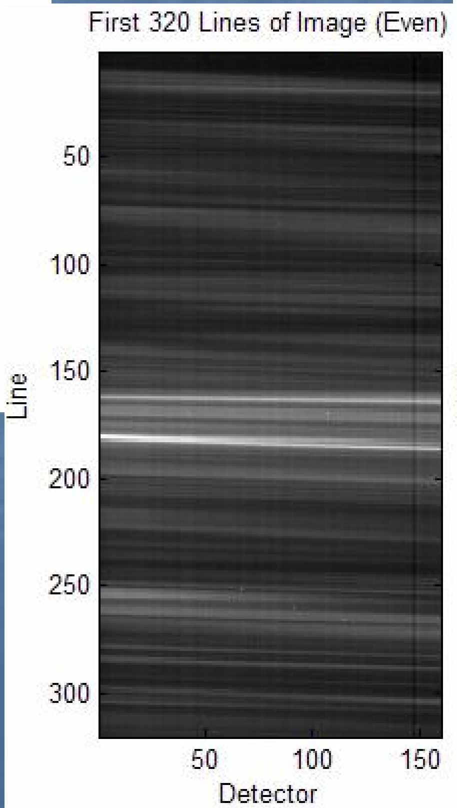
EO12002329141606_SGS SCA 1 Band 1p

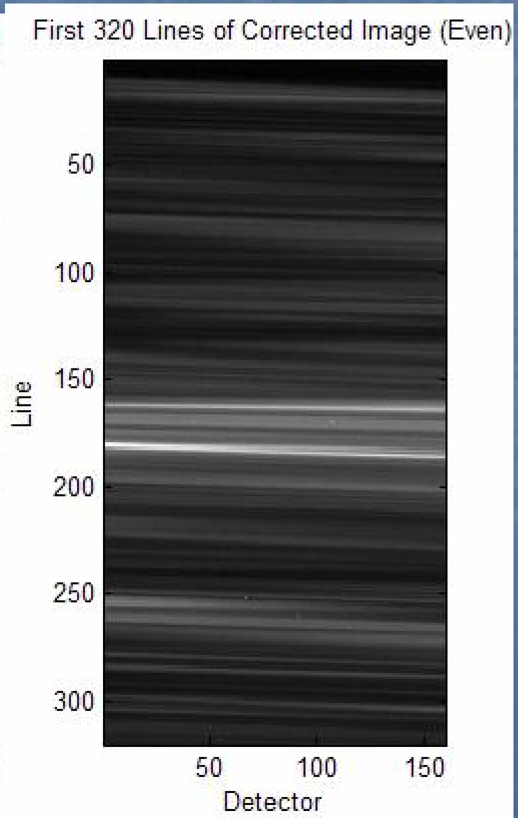




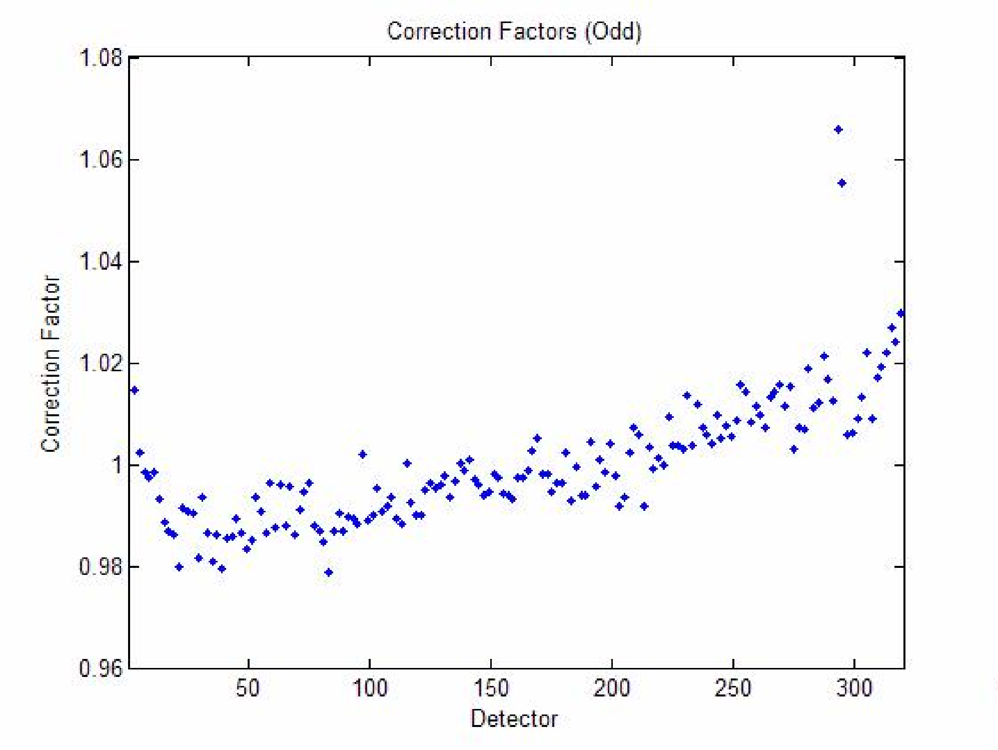
A 2nd example of a yaw image…

Yaw angle = 88.5°

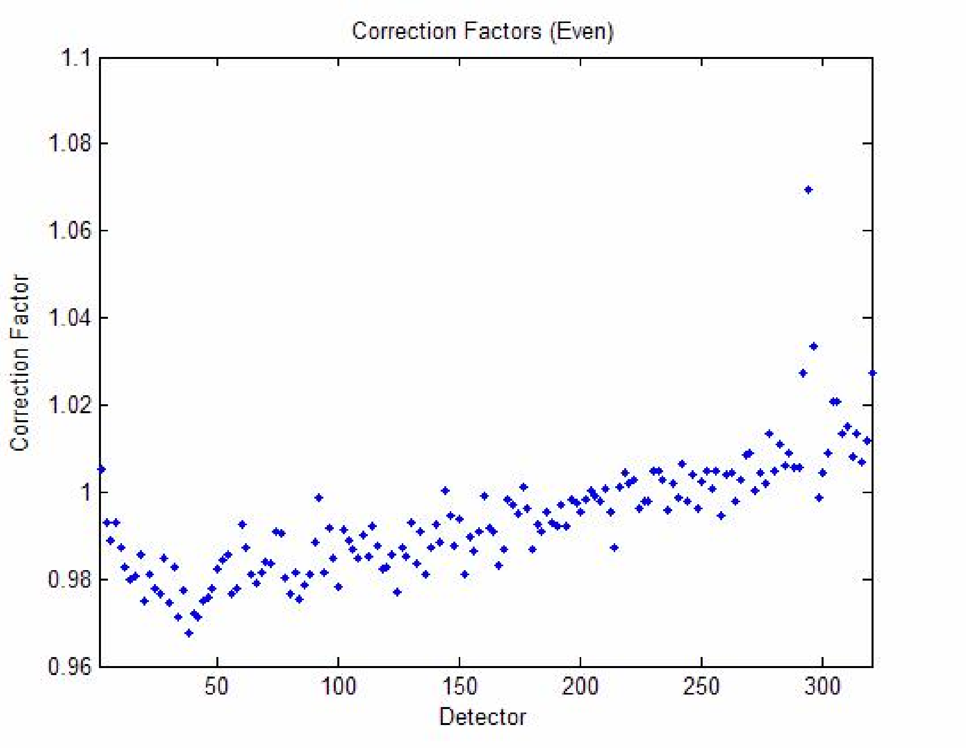




Band 1p Cont.



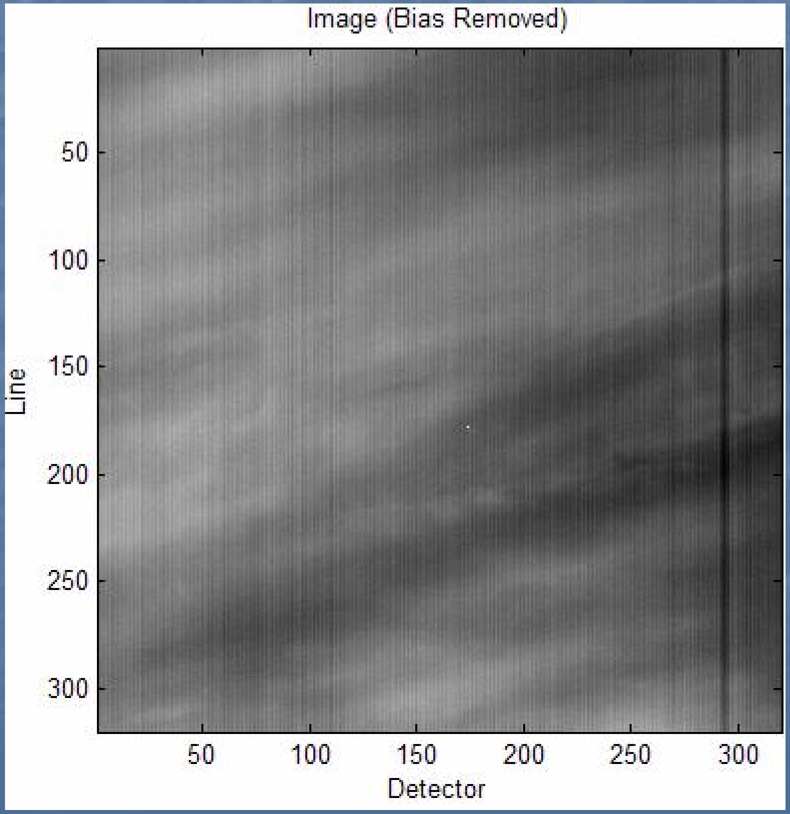
Correction Factors (Odd)
Correction Factor
Detector
1.08
1.06
1.04
1.02
1
0.98
0.96
50
100
150
200
250
300

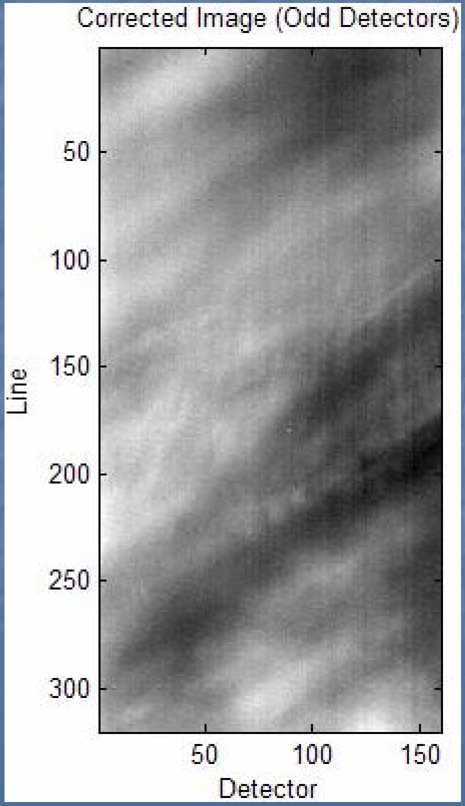


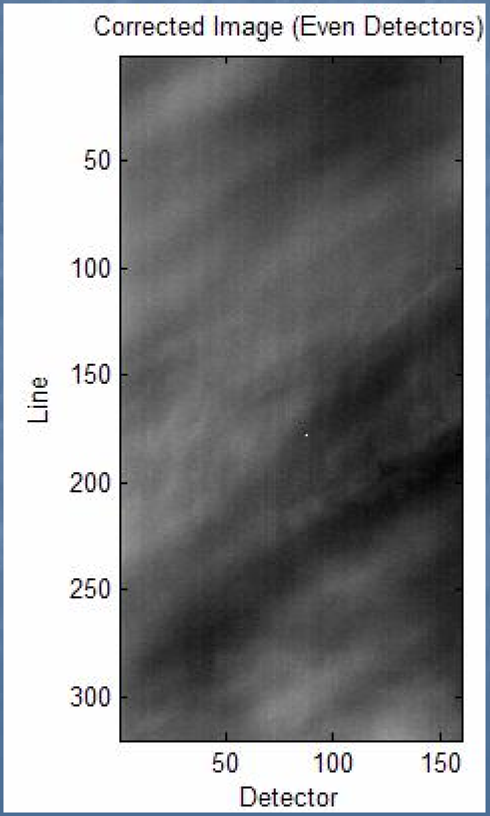
Correction Factors (Even)
Correction Factor
Detector
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
50
100
150
200
250
300

EO12002329141606_SGS Rel Gains Applied to EO12001059230136_PF1

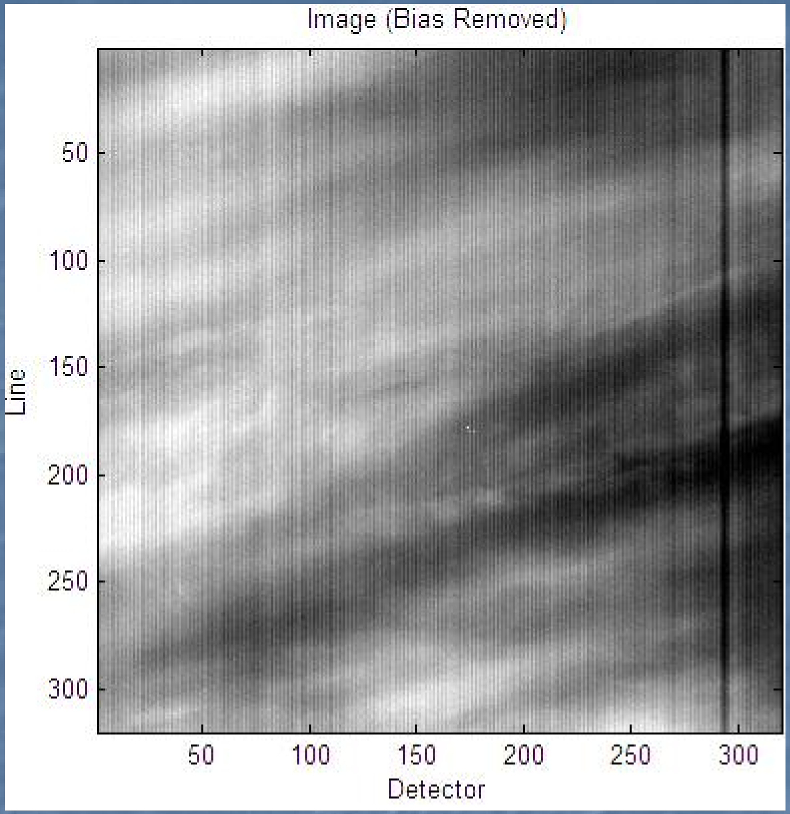
SCA 1 Band 1p



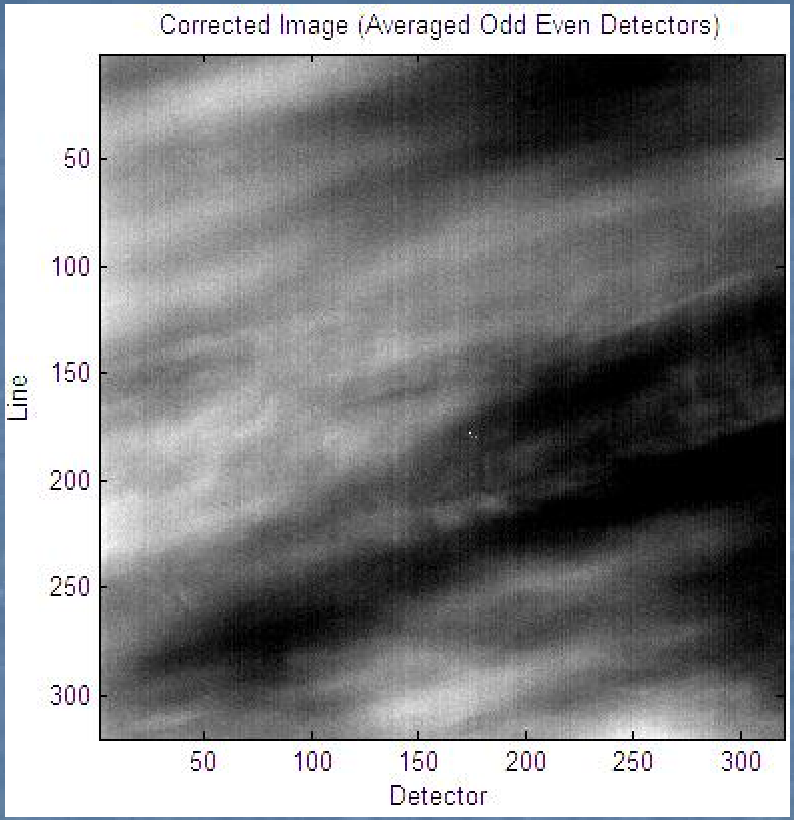




Band 1p Cont.



Data Range: 263-384



Data Range: 279-382

Even and Odd Detectors normalized by equalizing total means.

EO1200042621050 30_HGS

EO1200023291416 06_SGS

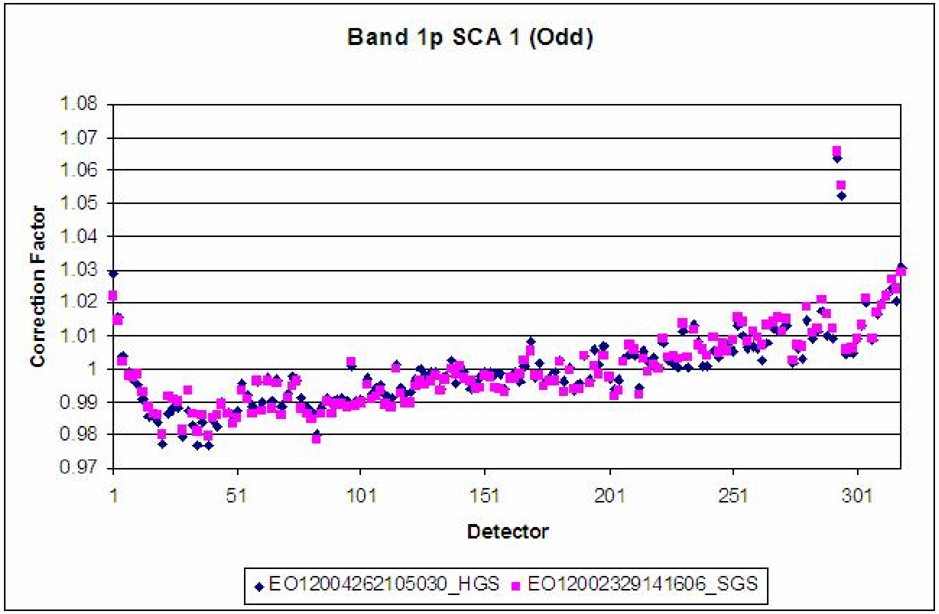
SCA 1 Comparison

EO12004262105030_HGS SCA 1

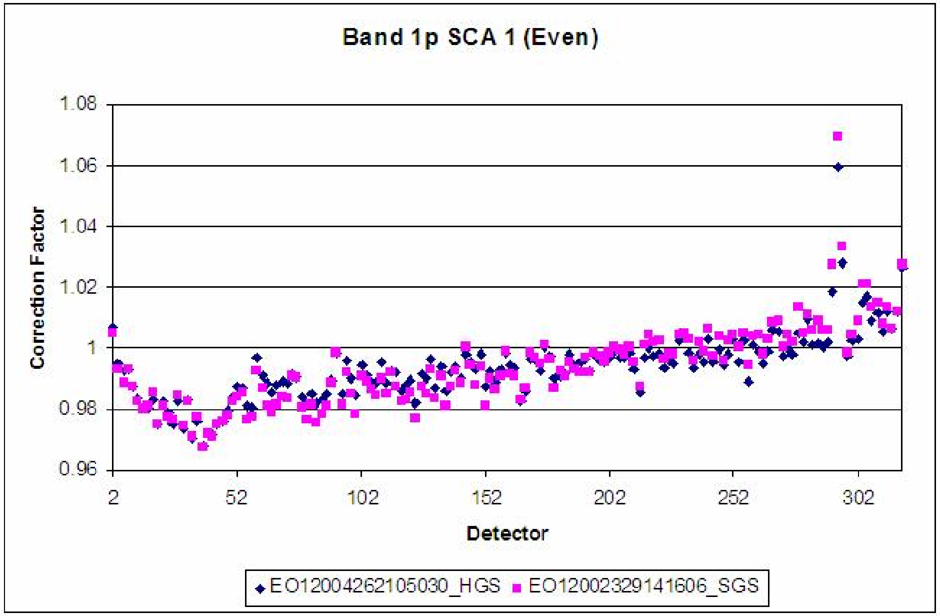
Band	1p	1	2	3	4	4p
Odd Ang. (deg)	88.2632	87.9966	88.8023	88.9465	88.9465	88.9322
Odd Overlap (%)	0.9385	0.9289	0.9578	0.9629	0.9629	0.9624
Even Ang. (deg)	87.9828	87.9966	88.418	88.65	88.65	88.6034
Even overlap (%)	0.9284	0.9289	0.9441	0.9524	0.9524	0.9507

EO12002329141606_SGS SCA 1

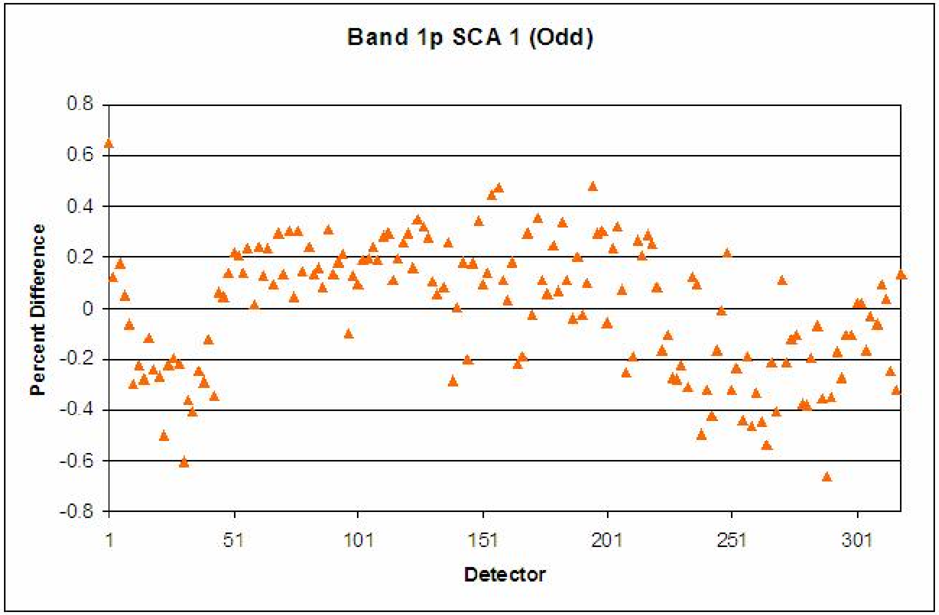
Band	1p	1	2	3	4	4p
Odd Ang. (deg)	88.54839	88.98058	89.16974	89.08163	88.9604	88.99361
Odd Overlap (%)	0.9487	0.9641	0.9708	0.9677	0.9634	0.9646
Even Ang. (deg)	88.43023	88.64094	89.10714	88.75984	88.69835	88.54317
Even Overlap (%)	0.9445	0.952	0.9686	0.9563	0.9541	0.9485



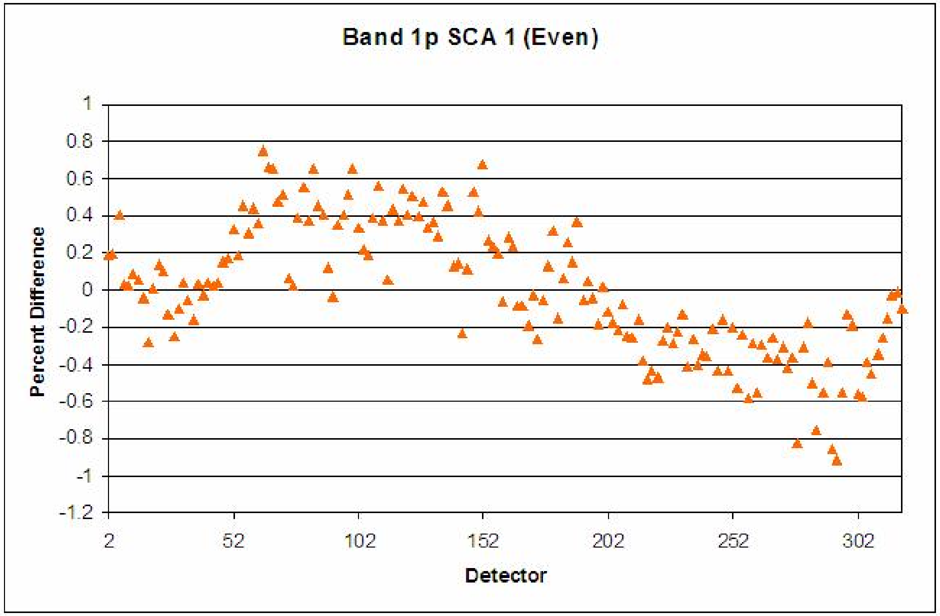
Band 1p SCA 1 (Odd)
Correction Factor
Detector
EO12004262105030_HGS
EO12002329141606_SGS



Band 1p SCA 1 (Even)
Correction Factor
Detector
EO12004262105030_HGS
EO12002329141606_SGS

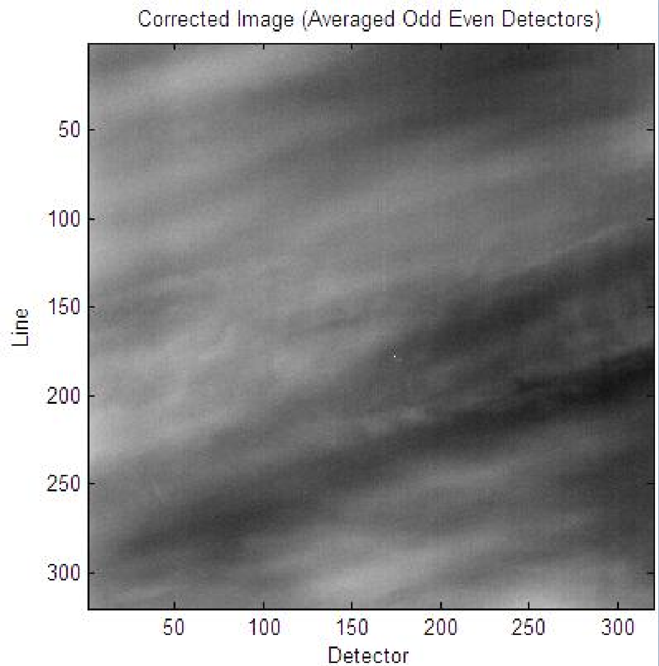


Band 1p SCA 1 (Odd)
Percent Difference
Detector



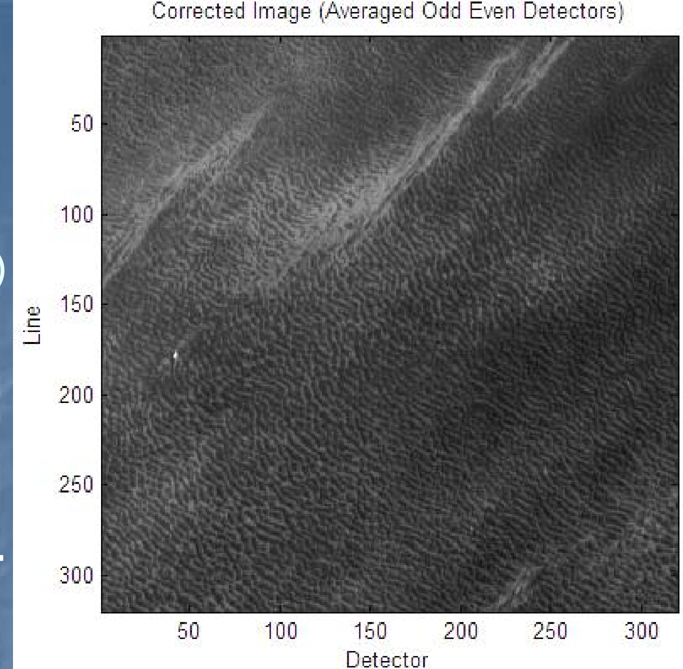
Band 1p SCA 1 (Even)
Percent Difference
Detector

Band 1p SCA 1



EO12004262105030_HGS
(upper images corrected by
2004 yaw scene-based gains)

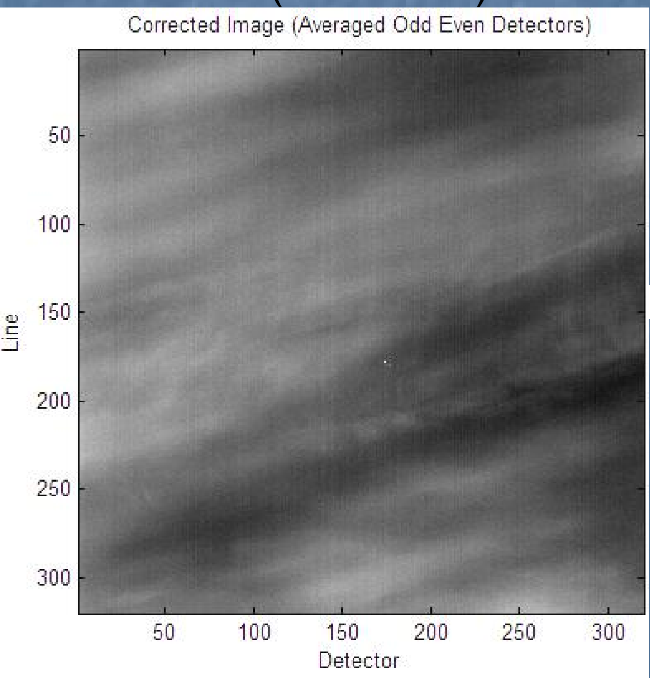
Data Range: 278-381



Data Range: 283-374

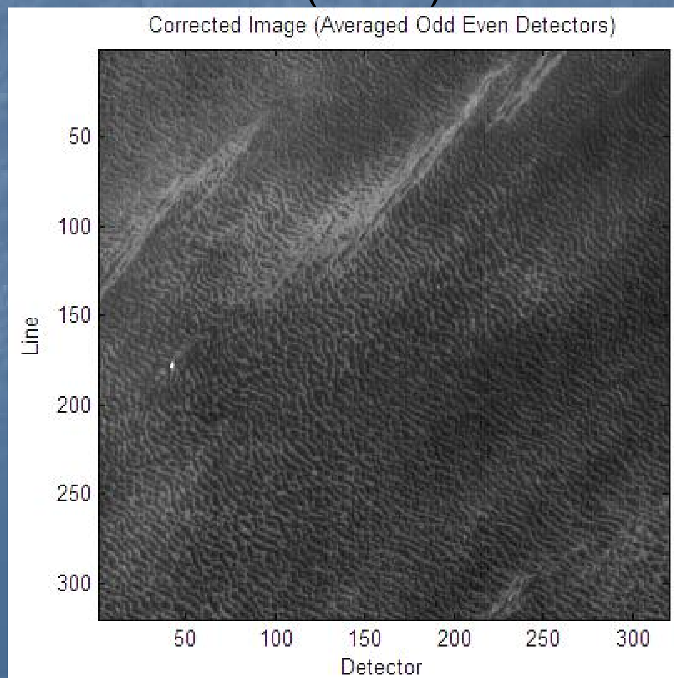
EO12001059230136_PF1
(Antarctica)

EO12004166105103_HGS
(Africa)



EO12002329141606_SGS
(lower images corrected by
2002 yaw scene-based gains

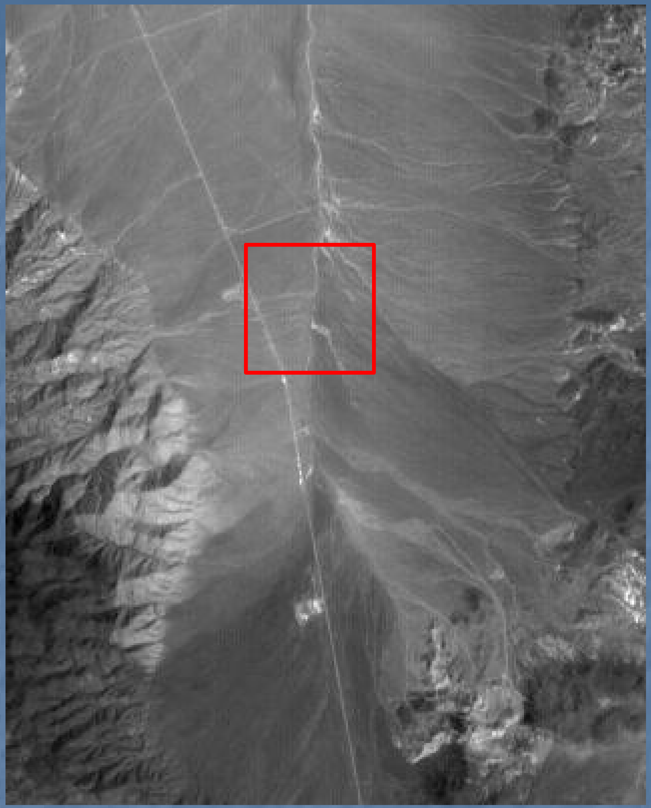
Data Range: 279-382

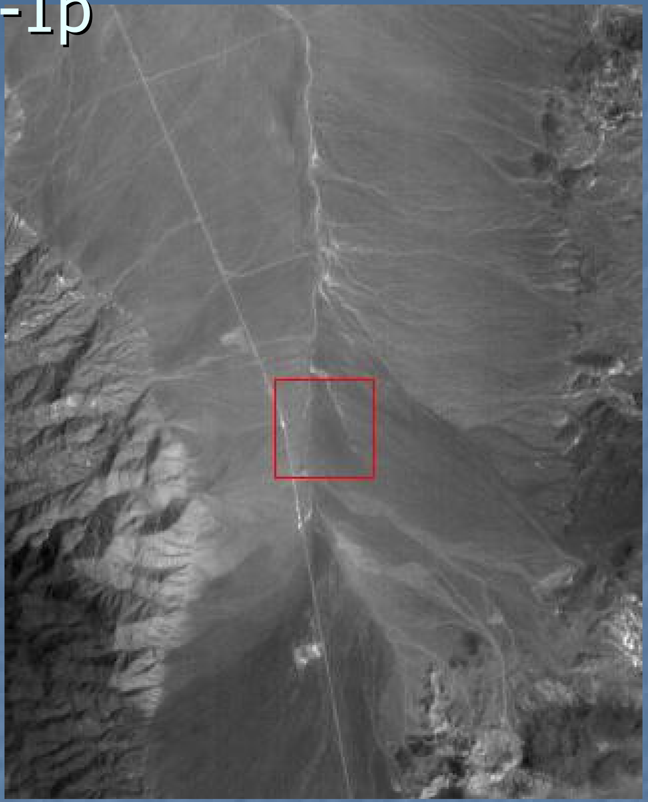


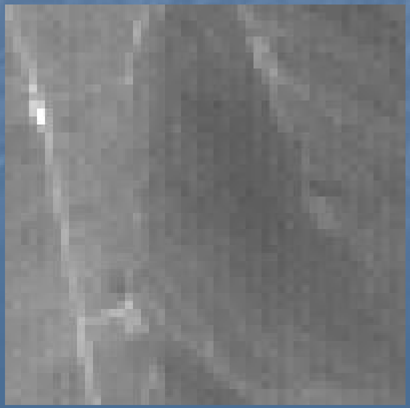
Data Range: 283-373

EO12001227182254_AGS_01

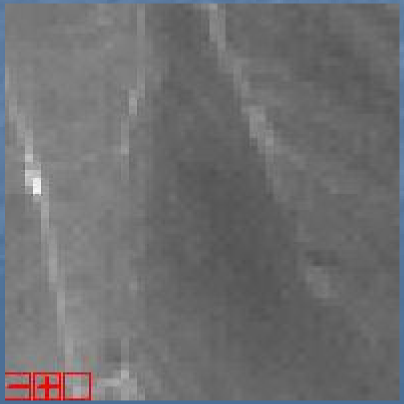
SCA 1 MS-1p



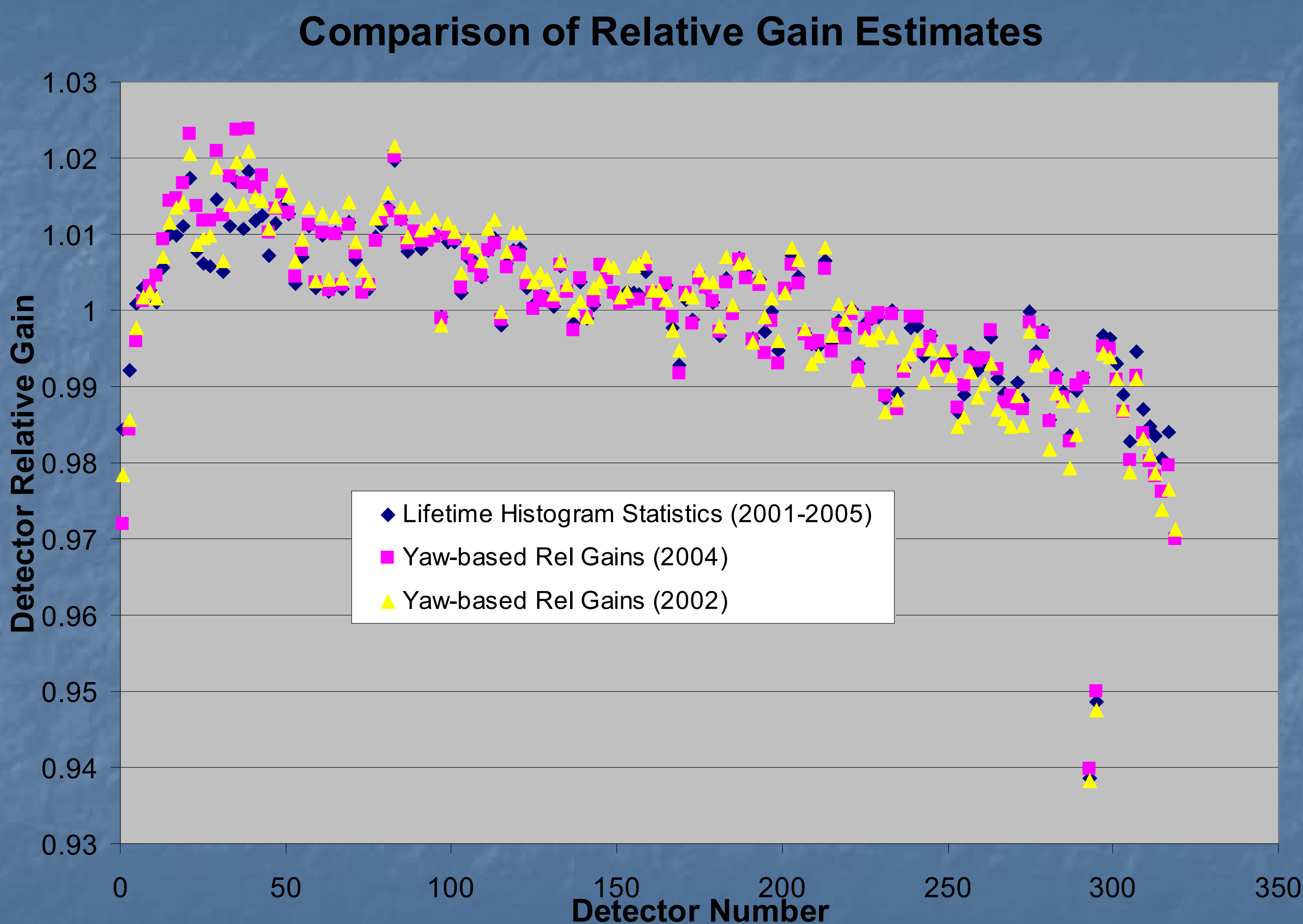




Lifetime Histogram Statistics Correction



Yaw Image-based Correction


Comparison of Relative Gain Estimates
Detector Relative Gain
Detector Number
1.03
1.02
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0
50
100
150
200
250
300
350
Lifetime Histogram Statistics (2001-2005)
Yaw-based Rel Gains (2004)
Yaw-based Rel Gains (2002)

Summary Points

- Lifetime statistics provide good information of overall relative gain trends within an array
  - Assumes relative gains only vary slowly with time
  - May require 'fine tuning' to optimize estimates
- Individual scene statistics approach is optimal with regard to visual removal of striping
  - Addresses problem of small, short term relative gain drift
  - Needs to be adapted to longer duration data sets
  - May be excellent for use with yaw images
- Use of imagery collected during 90^{o} yaw maneuvers can provide excellent information on detector gains
  - Need to image uniform surfaces
  - Should be executed on a regular (monthly to quarterly?) basis
  - Can be done with minimal impact to normal imaging by considering polar regions and possibly deserts.